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Report of the Advisory Panel to the

Mathematical and Information Sciences Directorate

Air Force Office of Scientific Research

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Advisory Panel to the Mathematical
and Information Sciences Division,
Air Force Office of Scientific Research
Board on Mathematical Sciences
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

The Advisory Panel to the Mathematical and Information Sciences Directorate of the Air Force Office of Scientific Research (AFOSR) serves under the National Research Council Board on Mathematical Sciences. The Advisory Panel was instituted in 1986 at the request of AFOSR, to "provide independent, high quality scientific evaluation of the Mathematical and Information Sciences programs" at AFOSR, and to provide "expert opinions about the merits of various fields of interest." The Advisory Panel was charged specifically with appraising the balance and general effectiveness of the programs of the Mathematical and Information Sciences Directorate and preparing recommendations and suggestions in response to questions such as the following:

1) Do research plans address critical technical issues within the scope of the mission of the Directorate?;

2) Is the planning adequate for the near term and for the long term?;

3) Is the work appropriate and effective in reaching the objectives of the program?; and

4) Is the research work itself at the state of the art? What is the quality of the investigators being supported?

To assess the array of programs represented in the Mathematical and Information Sciences Directorate, the membership of the Advisory Panel was chosen to reflect a wide range of interests and experience in mathematics and computer science.

The Advisory Panel held two meetings with AFOSR personnel at Bolling Air Force Base in Washington, D.C. In the first of these, held in October 1986, the Panel was briefed by the AFOSR Commander and Technical Director on the needs of the Air Force technology base and the goals and procedures of AFOSR; by the Acting Director of the Mathematical and Information Sciences Directorate on the role and activities of the Directorate; and by the managers of the 10 programs represented in the Directorate. The Advisory Panel divided itself into three subpanels, each charged with detailed examination of several of the Directorate's programs. After some preliminary work, the Panel met again in April 1987, when each subpanel conducted extensive discussions with the cognizant program managers. These discussions form the basis of the reviews of the ten programs presented in this report.

In addition to appraisals of the programs, this document presents some general observations and recommendations regarding the Directorate's activities. These comments are not intended to be exhaustive in commenting on every possible aspect of the Directorate's operations. In keeping with the Panel's mandate, the emphasis is primarily on the scope and quality of the research programs. Where possible, suggestions for future directions and opportunities are offered in areas that offer potential for advances in basic research, as well as relevance to Air Force technological needs.

CONTENTS

SUMMARY

The Advisory Panel finds the Mathematical and Information Sciences Directorate to be generally in a state of good health. The basic research programs of the Directorate address critical technological needs of the Air Force and are of considerable importance to the national research effort in mathematics and computer science.

An ongoing core research program is the major component of the Directorate's funding activities. The research programs are selective and make extensive use of peer review procedures. The overall quality of the research being supported is high. Connections with Air Force laboratories provide motivation of research areas and potential for collaboration.

An opportunity for strengthening the infrastructure of mathematics and computer science is perceived in increased support for graduate and postdoctoral students.

Each of the 10 research programs of the Directorate is reviewed in some detail. A number of research areas are suggested as having high potential for fundamental advances. These include (but are not limited to) robotics; VLSI signal processing; design of compilers, operating systems, and environments friendly to scientific computing; the mathematics of materials science; and mathematical design techniques for very high speed flows.

OVERVIEW OF THE MATHEMATICAL AND INFORMATION SCIENCES DIRECTORATE

INTRODUCTION

The Air Force Office of Scientific Research (AFOSR) is the single manager of the Air Force Defense Research Sciences Program. AFOSR is responsible for planning, implementing, and managing a high quality basic research program. The goals of AFOSR include the maintenance of strong science and technology infrastructure in Air Force laboratories, universities, and industry. To meet this goal, AFOSR manages an extramural research program at universities, nonprofit and industrial research organizations, and also provides overall management for research conducted on-site and under contract at Air Force laboratories.

The Directorate of Mathematical and Information Sciences accounts for about 10 percent of AFOSR's annual expenditures, a percentage that has been relatively stable over AFOSR's recent history. The Directorate supports research in applied mathematics, statistics, and computer science in areas of potential benefit to the Air Force. Research is motivated by problems such as the following:

. control of aerospace systems, including aircraft and large space structures;

. fluid dynamics and combustion (modeling of basic phenomena such as turbulence, and design of accurate and robust computational methods);

. nonlinear optics;

. optimization and combinatorial methods for aircraft design, resource allocation and scheduling;

. communications and signal processing;

. reliability and maintainability of complex systems; and

. storage of and access to knowledge data bases, e.g., by expert systems.

THE ROLE OF AFOSR IN FUNDING OF BASIC RESEARCH IN MATHEMATICS AND COMPUTER SCIENCE

The Mathematical and Information Sciences Directorate is an important source of funding for U.S. researchers in mathematics and computer science. Most of this funding is provided through ongoing core programs of research; in recent years, new initiatives have augmented most of the core programs. The Directorate carries out a broad program of research in applied mathematics, accounting for about 25 percent of total federal research expenditures in this area. In probability and statistics, the Directorate accounts for more than 20 percent of the federal effort. In computer science and artificial intelligence, support provided by AFOSR is more narrowly focused, but it is not an insignificant portion of the total federal effort.

The Directorate's extramural funding (exclusive of Air Force laboratories) is divided into 10 "tasks" or programs. A list of these programs, the names of the program managers (as of April 1987), and FY 1987 funding levels are given in Appendix I.

In FY 1987, the Mathematical and Information Sciences Directorate provided about $18 million of support for basic research in applied mathematics, probability and statistics, and computer science (including artificial intelligence). The vast majority of this support is in the form of grants to university-based researchers.

The average annual grant size in mathematics is about $60,000, and about $75,000 in computer science. There are a few very large multi-investigator grants at "centers" in several of the programs, frequently with some funding for visiting scholars. Except for the smallest ones, most grants provide some support for one or more graduate research assistants or postdoctoral research associates. In recent years, the principal means of program growth has been through the mechanism of "initiatives." Each Directorate within AFOSR is invited to present a case for increased funding in areas thought to be particularly promising for an infusion of support; several of these are funded as "initiatives." Successful initiatives are folded into the core programs after the first year, so that funding is maintained at the enhanced level. The Mathematical and Information Sciences Directorate has been relatively successful in maintaining its budget share within AFOSR under the initiative mechanism. An active role by the program managers is essential to this success. The program managers serve as advocates for their programs in particular, and for

mathematics and computer science in general. Their ability to develop and present a case for the potential payoff of a research area is critical to maintaining and enhancing funding levels.

One addition to AFOSR traditional funding modes deserves special mention. The University Research Initiative (URI) program was funded at the level of $2.86 million for FY 1987 by the Mathematical and Information Sciences Directorate. Five projects were funded (so-called "URI centers of excellence"), each involving several investigators. (See Appendix II for a list.) Several of these projects were examined in some detail during the Advisory Panel's review; the quality of work was found to be very high. If the URI program is not continued by Congress in FY 1988, the Panel recommends that the Directorate give serious consideration to alternative means of supporting the research areas represented in the URI program.

The Mathematical and Information Sciences Directorate is committed to the support of basic research in mathematics and computer science. The Advisory Panel believes that it is important that it be understood by the research community that the exploration of fundamental science, not development, is the role of AFOSR. In the case of mathematics and computer science the output of such research is usually generic, and the precise timing and nature of the impact cannot be predicted. Although the Directorate funds research that it considers relevant to Air Force needs, the judgment of such relevance needs to be made with a long-term perspective in mind and with a healthy respect for the tendency of mathematics and computer science research to turn out to be useful in unanticipated ways. Some further thoughts of the Panel on AFOSR's role are presented in Appendix III, which discusses in some detail the importance of basic research in applied science.

IMPACT OF THE DIRECTORATE'S RESEARCH ON AIR FORCE TECHNOLOGY NEEDS

AFOSR-funded research in mathematics and computer science addresses critical Air Force needs. A list of some of the problems motivating AFOSR's research has already been given; in these and other areas, mathematics supplies the basic tools for attacking the problem, and computer science is of fundamental importance in designing and implementing methods of computation suitable for large, complex problems.

The Air Force maintains a substantial number of research and development laboratories, which are an important bridge between basic science and Air Force applications. In addition to the research funded by the Mathematical and Information Sciences Directorate at universities and private research organizations, a number of "tasks" are funded at Air Force laboratories. Some of the laboratories in turn manage small extramural research programs. The total AFOSR funding managed by the laboratories in FY 1987 is about $2.1 million, of which about $1 million is disbursed by the Northeast Artificial Intelligence Consortium managed by Rome Air Development Center.

The mission orientation of AFOSR provides motivation for much of the research funded by the Directorate. This connection, and the lack of sharp disciplinary boundaries within mathematics and within computer science, permits program managers to take an activist role in relating the interests of their principal investigators to the needs of Air Force laboratories and contractors. It offers the potential for both academic researchers and laboratory and industrial scientists to learn and to collaborate in useful ways. Development of good contacts with laboratory scientists is an important part of the program manager's responsibilities.

PROPOSAL REVIEW AND SELECTION PROCEDURES

All of the programs of the Mathematical and Information Sciences Directorate receive a substantial number of unsolicited proposals. The number of high quality proposals received far outruns the available funding. For example, of 30 proposals received by Dynamics and Control in the last year, 20 were of high quality, but only 10 could be funded. In Probability and Statistics, only 7 new "starts" could be funded from nearly 50 proposals.

Funding decisions are the responsibility of the program manager. Every program in the Directorate makes use of peer review in evaluating proposals. The number of reviews of each proposal varies, with some programs routinely using four to six reviewers, and others more often using two or three. The Advisory Panel regards the use of peer review procedures by the Directorate as very important in ensuring impartial selection of high quality proposals, and strongly endorses the continuation of peer review in proposal evaluation.

OPPORTUNITIES IF MORE FUNDS WERE AVAILABLE

In the reviews of individual programs, a number of areas are singled out as opportunities for future thrusts. The Panel believes that important advances in mathematics and computer science are possible in the near future in these areas. Some of these would be appropriate candidates for major initiatives. For example, suggested new work in robotics (Subpanels I and II) and the mathematics of materials sciences (Subpanel III) would clearly be in this category. Certain other suggestions are aimed more at broadening the scope of existing programs than at defining major new directions. In the smaller programs in particular, where the scope of the program has been deliberately limited because of funding constraints, many proposals with good new ideas but falling outside the targeted areas, go unfunded. The coverage of these programs could be increased with no sacrifice in research quality.

Maintaining U.S. preeminence in the mathematical and computer sciences depends critically on the continued inflow of highly talented young scientists into these fields. The need for providing adequate graduate student and postdoctoral support in the mathematical sciences was highlighted and documented in the "David Committee" report.[1] That report further noted that the amount of this support, especially at the postdoctoral level, was considerably lower in the mathematical sciences than in several other scientific disciplines.

As noted earlier, many of the Directorate's grants make provision for support of graduate and/or postdoctoral students. These training positions are found mainly in larger grants and contracts, and are concentrated at major universities, especially at the URI centers of excellence. As additional funds become available increased resources for training positions could pay big dividends. This is particularly appropriate for applied mathematics and statistics programs in view of the especially suitable conditions for group efforts and the documented shortage of training positions in these areas.

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[1] Renewing U.S. Mathematics, Critical Resource for the Future, National Academy of Sciences/National Research Council, Ad Hoc Committee on Resources for the Mathematical Sciences, E.E. David, Chairman. National Academy Press, 1984.

REPORT OF SUBPANEL I

Herman Chernoff
Wendell H. Fleming
Thomas Kailath
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INTRODUCTION

The four areas reviewed by this subpanel are of fundamental importance to the scientific and engineering community. Dynamics and Control, as the name clearly suggests, is concerned with the control of dynamic, that is, time-varying, systems. A criterion, or an objective, is used to measure how well the control is being carried out, under a system description often expressed in terms of constraints. This is very closely related to the fundamental problem of Optimization, which consists of minimizing or maximizing an objective function subject to inequality constraints. Taken together these two areas encompass an enormous number of problems both theoretical and practical in nature, ranging from the optimal control of flight trajectories and manufacturing processes to optimal design and scheduling in computer and transportation networks.

Since most real-life problems contain elements of uncertainty, the field of Probability and Statistics is fundamental to almost every scientific endeavor and especially to the areas of Dynamics and Control, Optimization, and Signal Processing, all reviewed in this section. Thus the field of Probability and Statistics, important in its own right, finds application in such diverse problems as stochastic control and optimization, pattern recognition, information theory, artificial intelligence, and queueing theory. Stochastic methods are also of great importance in Signal Processing, an important area of applications of Air Force interest. The highly interdisciplinary nature of the Signal Processing field makes it a ripe area for contributions from control theory, computer science and other fields.

Each of the four programs reviewed in this section has a rich diversity with a distinct subdisciplinary identity. However, they also share many important characteristics that enable us to look at them as highly interrelated fields.

DYNAMICS AND CONTROL

The name "mathematical control theory" refers to a collection of methods used to study models of real control systems arising in engineering practice and the sciences. The objective is to adjust certain control inputs to the system, either off-line or dynamically in real time, to obtain "good" system performance according to some criterion. The mathematical control theory field is distinctly interdisciplinary, depending on a judicious blend of modeling, mathematical analysis and computation.

Among the factors influencing the development of this field are changing technological needs, dramatic increases in available computing capabilities, and developments in such related mathematical fields as partial differential equations, stochastic processes, optimization and geometry.

The AFOSR program in dynamics and control emphasizes four areas: adaptive control, stochastic control, robust control, and distributed parameter control. Adaptive control theory is concerned with the simultaneous identification and control of unknown system parameters in real time. It has long been recognized that feedback controls must be used to obtain good system performance in the presence of disturbances. If the disturbances are modeled as random processes, then the control model is stochastic with feedback controls based on best estimates of the state. Robust control seeks to achieve good performance in the presence of model inaccuracies or system changes (e.g., through a breakdown). About half of the research effort supported through the Dynamics and Control Program is in distributed parameter control, which concerns systems whose dynamics are governed by partial differential equations. Current emphasis on distributed parameter control theory is motivated by Air Force technology needs in such areas as space structures, adaptive optics, aerodynamics, and combustion.

Program Review

AFOSR is a major source of research support for mathematical control theory. Its program ($3.09 million in FY 1987) is the largest in this area among the various federal government agencies. The main areas of current research in control are well represented and address well Air Force technology needs. The Dynamics and Control Program has been vigorously managed during recent years. The quality of the research supported is high. In the mix of projects being supported there is a good balance among the various aspects of research in the control field--modeling, mathematical analysis, and computation.

The Dynamics and Control Program has useful connections with a number of Air Force centers. For example, it supports guidance and control work at Eglin AFB and work on robust methods for multivariate control at Wright-Patterson AFB. A workshop in control theory and fluid mechanics, to be held at Wright-Patterson in September 1987, was organized by AFOSR.

Under discussion is an initiative in robotics to be jointly sponsored with the Electronics and Material Sciences Directorate of the AFOSR. This would be a highly promising and timely initiative, which would bring to bear the powerful theoretical and computational machinery of optimal control theory on the fast moving and important field of robotics. The related area of CAD-CAM would also benefit a joint sponsorship by the Dynamics and Control Program and the Electronics and Material Sciences Directorate.

Despite its relatively large size, the Dynamics and Control Program funds only single researchers or pairs of researchers as principal investigators. This appears to be an entirely adequate procedure. The standard for successful proposals has been high and should be maintained at that level.

Conclusions and Recommendations

The AFOSR has taken a leading role in the support of control theory research. There will be a continuing need for advanced control methods to deal with challenging technological problems of concern to the Air Force. Systems of greatly increased complexity are being constructed. Performance requirements and design criteria are becoming stricter. Vastly increased computing power and new computer architectures are available for control implementation. In addition to control of physical devices and processes, there are various problems ofcontrolling "man-made" systems, such as flow and routing in data communications networks, scheduling of complex manufacturing operations, and air traffic control. In the management of man-made control systems, there is often a hierarchy of decision levels whose interactions are difficult to model.

In planning future directions for the Dynamics and Control Program, the following may represent areas of significant opportunity:

1. Robotics. Among the many facets of robotics research, several are related to control theory or signal processing, including: robot motion control, computational vision, image reconstruction and robot structural design.

2. Optimal shape design, for example of airfoil shapes, engine parts, and load-bearing structures. This area is closely related to distributed parameter control and also to the Optimization Program.

There are other topics in which fundamental theoretical advances would have significant impact on technological applications. One such topic is control and information processing in a decentralized environment in which processors at physically separate locations share information. Another broad topic is the modeling and control of discrete event dynamical systems. This topic has an artificial intelligence (AI) aspect, being concerned with models less well structured than is usual in mathematical control theory. Another aspect for which the mathematical models are more explicitly formulated concerns stochastic control of discrete event systems such as queueing networks.

COMMUNICATIONS AND SIGNAL PROCESSING

The field of signal processing explores the problems of defining appropriate processing operations to be applied to classes of signals (functions of one or more variables) in order to efficiently extract "information" contained in the signals. Applications are legion in a variety of fields, including many of direct interest to the Air Force.

Spectral analysis has long been a favorite tool for signal processing, and was given special impetus by the recognition of the FFT (Fast Fourier Transform) algorithm. The FFT sparked a lot of mathematical work on the general properties of fast transforms. Important insights into the workings of the FFT have been gained by means of methods from group theory, number theory, and algebraic geometry.

Since the late 1970s, the field of signal processing has broadened considerably, especially with the recognition that modern electronic technology offered the promise of actually physically implementing very large and complex computations. Signal processing offers one of the most promising areas of application of the newest generation of technology.

As a result of these developments, signal processing has entered a period in which it has become highly interdisciplinary. Specialists in analog and digital circuit design and fabrication, communications theory, statistics, numerical analysis, computer science, control

theory, and various applied fields must today cooperate as never before. The interchange has already been two-way: signal processing has profitted from many ideas in these fields and conversely has contributed new problems and sometimes new results to mathematics and to the other fields named above.

Evidence of renewed interest in signal processing may also be seen in the series of workshops and institutes in signal processing planned over the next year by Society for Industrial and Applied Mathematics (SIAM), the Institute for Mathematics and its Applications, and NATO.

Program Review

While research in statistical communication theory and on various specific signal processing problems has long been supported by AFOSR, increasing awareness of the range of disciplines arising in signal processing and of the scope and vitality of the field led AFOSR a few years ago to form a new program entitled the Mathematics of Communications and Signal Processing.

AFOSR started this new program by putting together several existing grants, mainly in probability and statistics, mathematics of computation, dynamics and control and computer science. This unavoidably resulted in a rather heterogeneous new program, roughly organized under three major headings: robust procedures for signal detection and estimation, image restoration and quantization schemes, and prediction and filtering for non-Gaussian and dependent signals. The total funding for the program in FY 1987 is $0.87 million, making it one of the smaller programs in the Directorate.

As existing grants expire, it would be desirable to slowly reshape the program with an eye toward opportunities for joint efforts, both within the Mathematical and Information Sciences and with other Directorates, especially Electronics and Material Sciences. In this regard, we note that signal processing research can overlap substantially with the new FY 1989 initiatives in inverse problems and in parallel optimization.

Conclusions and Recommendations

The time is opportune for vigorous reevaluation, redirection, and reorganization of AFOSR's efforts in this important area, with the goal of enhancing the depth and significance of the research and increasing the research training function through greater support of postdoctoral and graduate students.

In addition, there is potential for further development of the (as yet rather minimal) interactions of the new Communications and Signal Processing Program with Air Force laboratories. In addition to existing contacts with Rome Air Development Center, opportunities for contacts could be explored both with other Air Force labs (e.g., Hanscom) and perhaps also with heavily Air Force sponsored organizations such as the M.I.T. Lincoln Lab, Mitre Corporation, and Aerospace Corporation. The aim should be not so much input on specific research problems, but rather guidance on fundamental problems that need attention.

Some areas in which fundamental research could be initiated or strengthened are as follows:

1. VLSI Signal Processing: The joint exploration of algorithms and architectures for very high speed integrated parallel and distributed signal processing.

2. Space-Time Signal Processing: As in adaptive antenna arrays for radar, sonar and in general image processing, including computer vision.

3. Non-Gaussian Signal Processing: Using higher-order statistics to get beyond existing signal processing and system identification methodologies.

In planning how to follow up on its initiation of the new program in signal processing, some mechanism such as a series of workshops should be considered. To better identify research opportunities, two or three workshops bringing together leading researchers from universities and the large Air Force community may be worthwhile. Initially, this could be made part of the AFOSR activities at one of the sites of large grants with a significant component of activity in signal processing. This activity might be pursued jointly with the Electronics and Material Sciences Directorate.

In longer-term planning, it is perhaps worth drawing attention to the notes of a one-day signal processing workshop held at AFOSR on August 16, 1984. One of the suggestions therein was the possibility of establishing one or two Signal Processing Research Institutes. One role of such institutes could be to provide a focus for periodic conferences and workshops to bring together the many communities interested in signal processing and to help guide and stimulate appropriate research directions.

OPTIMIZATION

Optimization received its modern impetus with the discovery in 1947 by George B. Dantzig of the simplex method for the efficient solution of linear programs that arose, interestingly enough, from Air Force planning problems. The fundamental distinguishing feature of modern optimization theory is its combinatorial aspect which is mandated by the presence of inequality constraints in the problem. Optimization theory covers a wide range of topics such as allocation problems, scheduling production, inventory problems, approximation problems, game theory, network flow problems, transportation problems, and many others. Many of these problems are of fundamental importance to industry, the military, and the scientific community at large. Accordingly, a strong research program in optimization is of great national benefit.

Program Review

The AFOSR Optimization Program is a new program begun in 1985. With a FY 1987 budget of $1.1 million and 16 grants, this program has managed to make a significant impact on the optimization community. Noteworthy among these grants are those on large scale and parallel optimization, stochastic optimization, stochastic dynamic systems, numerical methods for optimization, and constrained optimization. Perhaps a good indication of the strength of this program is the calibre of researchers that it is attracting and supporting.

With its limited budget the Optimization Program cannot possibly cover all the significant and emerging areas in optimization. However, by possible increase and/or shift of funding, other important areas could also be supported, such as parametric optimization, combinatorial optimization, and optimal design.

The program manager has begun to establish contact with various Air Force branches that could significantly benefit from the optimization research being sponsored. Typical examples are the Military Airlift Command for use of large scale transportation algorithms, Wright-Patterson AFB for use of structural design optimization, and other branches that could make use of decision theory results such as those on multicriteria optimization, and game theory.

Most of the grant recipients in the Optimization Program are well established senior researchers; there are a few promising recent Ph.D's. While this may be a reasonable initial strategy for maximum impact on the field, increased additional participation of young researchers as PI's, post-docs or graduate research assistants is encouraged.

An initiative in Parallel Optimization, scheduled for $350,000 in FY 1989, is a very timely and important initiative in which the AFOSR already has the lead on other research organizations. The rapidly emerging parallel architecture technology will, in all likelihood, revolutionize the greater part of computational mathematics. The huge optimization problems that appear in the real world are excellent candidates for testing both the various parallel architectures and new parallel optimization algorithms. Other possible future initiatives might be in the area of stochastic optimization, structural optimization, and combinatorial optimization.

The Optimization Program has a good working relationship with most of the other federal agencies funding research in this area. This is helpful in enhancing the funding impact of the program. These relations should be continued and expanded to other agencies.

Selectivity standards for funded proposals appear to be reasonable.

Conclusions and Recommendations

Despite the relatively small size of the Optimization program (sixth largest among the 10 programs), it appears that it has been vigorously and effectively managed. Its areas of emphasis are judiciously divided between established areas (such as constrained optimization) and novel approaches (such as Parallel Optimization), with the latter holding the greater promise of a significant breakthrough. Funding of the highly promising Parallel Optimization Initiative will increase the significant impact that this modest program is having on optimization research. In addition, the following areas hold the promise of significant research achievements in the area of optimization and hence should be encouraged:

1. large-scale linear and nonlinear programming algorithms;

2. nonsmooth optimization, that is, optimization problems involving nondifferentiable functions;

3. large scale network flow optimization.

4. penalty function methods;

5. polynomial-time algorithms for linear and quadratic programming;

6. nonconvex optimization;

7. complementarity problems and variational inequalities; and

8. stability of optimal solutions.

PROBABILITY AND STATISTICS

Probability and statistics are basic to other fields in science and technology. For example, signal processing, communication theory, stochastic control, and operations research have borrowed heavily from these areas. Insofar as statistics addresses the questions of scientific inference in general, it is relevant to all of science. In a less grandiose way, it is clearly relevant to technological questions of quality control, reliability, experimental design, testing, and prediction. It is essential that a healthy infrastructure in Probability and Statistics be maintained.

The Probability and Statistics Program at AFOSR contributes in this manner. It supports a strong program with emphasis in four areas: reliability, stochastic processes, multivariate analysis, and design of experiments. Reliability has been, for several years, a large part of the program. Here questions of reliability growth, maintainability, repairable systems, and the effects of dependent components have been addressed. Work in stochastic processes includes random fields, which is relevant to the new initiative in stochastic inverse problems, and nonlinear filtering, which is relevant to signal processing, plus a number of other topics in applied probability. Multivariate analysis attacks the problem of dealing with high dimensional data, which has application to pattern recognition, signal detection, and prediction. Finally, design of experiments is a field that originated in agricultural experimentation, and having had an enormous impact on the improvement of agriculture,has developed further in other scientific and technological applications. Some basic questions in this field are being addressed.

Program Review

This program, with a FY 1987 budget of $2.91 million, funds approximately 40 grants. Among the investigators being supported are many outstanding statisticians and probabilists. Most of the others are well known for their contributions.

The program continues to attract first-class scientists. Last year, a large number of proposals was submitted, with a relatively low "success rate."

The Panel has the impression that although these proposals being funded involve potential applications, there has been relatively little communication between the scientists and the Air Force laboratories and contractors. Since communication could play an important role in stimulating good science and enhancing the usefulness of this work, it would be desirable to find some mechanism for providing such communication.

About one third of the total funds for the Probability and Statistics Program is assigned to four relatively large grants or "centers." This seems to represent a reasonable balance between large and small contracts. Each of these centers concentrates primarily on one of the four major areas of program emphasis.

The current heavy investment in reliability is partly an outcome of a FY 1984 initiative, and it has led to a program that has a major impact, funding many of the leading contributors to that field. The stochastic process group of grants also represents a significant portion of the well-known researchers in that broad area. There is some current interest in seeing if it is possible to develop a comparable group of researchers in high dimensional data to supplement the work of the large grant in multivariate analysis.

Conclusions and Recommendations

The AFOSR Probability and Statistics Program makes a substantial impact in reliability and stochastic processes. The recent additions to the program tend to strengthen an already strong program.

The area of multivariate analysis with emphasis on high dimensional data and non-Gaussian models is growing and ems to be worth developing further. The current grants in multivariate analysis support a center with outstanding workers in that field. Further developments may provide AFOSR with the ability to have a large influence in that area. Moreover, this work may supplement and support the work in stochastic inverse problems, image analysis, signal processing, pattern recognition, and concurrent computing taking place in other areas supported by AFOSR.

Some effort should be given to communicating between Air Force laboratories and contractors and AFOSR, to better define statistical problems of interest to the Air Force, and to encourage research by the academic community in these areas. Workshops with a well-defined focus, such as the May 1985, Reliability Workshop at Luray, Virginia, can be useful in bringing together academic and laboratory scientists with common interests. Visits to appropriate Air Force laboratories by investigators could also serve to stimulate interest in applicable research.

REPORT OF SUBPANEL II

C. William Gear
Beresford N. Parlett
Michael O. Rabin
Stuart C. Shapiro

The four programs examined by Subgroup II--Computational Mathematics, Finite Mathematics, Computer Science, and Artificial Intelligence--consume over 40 percent of the budget of all programs in the Directorate. Each of these programs has clearly identifiable relationships to Air Force needs. A significant portion of the research supported is related to scientific computation, particularly in the Computational Mathematics and Computer Science programs. The hard sciences and engineering are concerned with prediction. The mathematical equations that model the systems of interest would lose much of their value if we could not solve them. Unfortunately, in most cases we cannot represent the solutions analytically. Nevertheless, we can sometimes coerce computers into disgorging approximations that are adequate. Scientific computation is concerned with inventing and analyzing methods for generating such approximations. Consequently, scientific computation is necessary for putting almost any of the mathematical sciences to work, so it is reasonable that research related to scientific computation consumes a considerable share of the Directorate's budget.

Computational mathematics is the most obvious aspect of scientific computation but it is only part of the enterprise. The Computer Science Program is heavily slanted towards scientific computation, as mentioned in more detail in the discussion of that program.

Discrete (or finite) mathematics is very different from classical analysis and the differential equations of applied mathematics. Finite mathematics involves inequalities and algebraic equations in its models, e.g., logistics, optimal placement of sites, and searching strategies: these are more applicable to Air Force problems of organizational management than to physics and chemistry. Nevertheless, solutions must be computed in order to profit from the models. Finite mathematics plays a key role in development of algorithms for computation, and in understanding their computational complexity, and thus is important to the foundations of computing.

In contrast to the first three programs, artificial intelligence (AI) currently has little to do with scientific computing. It is concerned

with ways to program a computer so that it functions in a manner attributed to intelligence when the agent is human. One good example is diagnosis (whether it be the mineral composition of rocks or the malady of a sick mammal). Another example is perception and interpretation of signals. A much more complete outline of the field appears below in the section on AI. It is apparent that some parts of the field have direct bearing on tomorrow's Air Force. The use of AI (via, e.g., expert systems) to help the scientific programmer is another possibility on the horizon.

COMPUTATIONAL MATHEMATICS

Overview

The objective of this program is the development and analysis of reliable, efficient algorithms for the solution of systems of equations and inequalities from various applications of interest to the Air Force. Major areas supported are numerical methods for ordinary and partial differential equations, computational linear algebra, and parallel algorithms. The aim is to strengthen the fundamental mathematical framework of the research topics and to implement these topics in algorithms and high level software. Applications of particular interest include simulation of aerodynamic and space structures, physical and chemical phenomena, including plasmas and combustion, and high-speed data processing.

Special emphasis is placed on large scale computations for approximating solutions of two- and three-dimensional problems arising in mechanics, physics, chemistry, etc., which involve complex systems of nonlinear partial differential equations. The algorithms developed should exploit and influence the design of emerging computer architectures. This motivates the interest in parallel numerical algorithms for execution on multiprocessors.

Program Review

This is the second largest program in the Directorate ($3.01 million for FY 1987). Nearly half is committed to methods for solving differential equations of various kinds (ordinary and partial). In addition, there are substantial commitments to solving algebraic equations and to parallel algorithms. There is coordination among the Computational Mathematics programs across DOD agencies. For example, while the Office of Naval Research also gives significant support to numerical fluid

dynamics, AFOSR has the major responsibility within DOD for research in matrix computations and matrix theory. In the area of numerical solution of partial differential equations, ONR covers vortex methods while AFOSR is nearing completion of a concentrated effort on automatic mesh generation algorithms (nearly $1 million over 5 years).

There seems to be a healthy variety in the size of the groups supported by the AFOSR Computational Mathematics Program and in their geographic location. The overlap with Computer Science is evident and even to be encouraged. However, there is a fuller discussion of the Computer Science scope in its subsection.

In close association with the research in Computational Mathematics is the AF lab task on development of parallel algorithms at the AF Weapons Laboratory. Strong emphasis is given there to performance evaluation and it seems attractive to extend that idea even to AI research topics. The other AF lab task at Wright Aeronautical Laboratories covers fluid and structural mechanics. This effort involves some of the PIs in this project, and the subpanel is pleased to see this cooperation.

The Computational Mathematics Program is a carefully orchestrated effort covering a wide variety of important research topics and the quality of the PIs is high. A new research area involving both this program and Computer Science is described at the end of this (Subpanel II) report.

FINITE MATHEMATICS

Overview

Areas of research in finite mathematics that are of interest to the Air Force include graph theory, combinatorics, enumeration and counting, coding, block designs, networks, lattice theory, partially ordered sets, combinatorial geometry, matroid theory, boolean algebra, extremal set theory, logic and automata, integer programming, polyhedral combinatorics, discrete optimization, switching theory, utility theory, scheduling theory, algorithms and complexity theory. Among the goals of the AFOSR Program in this area are development of theoretical tools and efficient algorithms for dealing with discrete problems, and construction of mathematical models applying discrete techniques to a variety of real problems. The research supported under this program is strongly motivated by applications in such areas as command, control and communications, computer science and computer engineering, and operations research.

Applications include VLSI design and layout, parallel computation, artificial intelligence, scheduling and allocation problems, design of communications networks, robotics, fault detection and error correction, stochastic optimization, and the design and analysis of efficient algorithms.

Program Review

This is the smallest program in the Directorate ($750,000 for FY 1987) and at least 80 percent of its budget goes to the support of two groups, one at Rutgers University, the other at M.I.T. What funds remain permit the support of about 2 individual investigators in the rest of the nation each year.

The reputation of the scholars associated with the program is first class. The center at Rutgers is broad in its scope, concerning itself with operations research, communication networks, placement problems, and decision trees. The group at M.I.T. is focused on parallel computing and distributed computing. Clearly there are links to investigators in other programs and these are to be encouraged.

The narrow concentration of the limited budget seems to the Subpanel to be completely justified. Some consideration could be given to whether Computational Geometry is sufficiently important to AFOSR goals to warrant initiating a research grant in this area, but not at the expense of current investigations. Another possible initiative area, already mentioned in the review of the Optimization Program, is combinatorial optimization.

COMPUTER SCIENCE

The Role of Computer Science in AFOSR Mathematics and Information Sciences

Computer science is a broad discipline that can loosely be defined as being concerned with information objects and their organization, reorganization, and processing. Because some of the objects studied are computer programs, programs are the form in which information processes are described, and computers are the laboratory instruments. There is confusion in the public mind between computer science and computer programming, resulting in a view of computer science as an applied, rather than basic, research area. Until the AFOSR funding for Computer Science increases drastically, it is unreasonable to expect to cover the spectrum of computer science. Instead, the programs should focus on areas of basic research that relate to other AFOSR programs and Air Force needs.

Mathematics of computation and, more specifically, scientific computation, plays an important role in the AFOSR program so it appears that the greatest near-term benefits from computer science will be from those areas that are currently roadblocks to the development of new algorithms and the use of new architectures in particular environments and systems.

It has been stated elsewhere that the interface between computer science and scientific computation is no different from the interfaces between computer science and other disciplines. It is our contention that this is not so, and that there is a major need in this interface that can be addressed by the AFOSR program. (A specific suggestion appears at the end of this Subpanel report).

Although, because of the diversity of computer science, there are areas not covered, those areas could not be covered without removing support from existing areas, so it is important to consider the program more as it relates to the rest of the Mathematics and Information Sciences Program rather than as a stand-alone computer science program.

Whereas some interfaces, such as computer science and chemistry, are simple applications of computer science, some are basic, for example, computer science and psychology in the artificial intelligence/cognitive science area. The scientific computing area suffers from the problem that both computer science and applied mathematics see it as merely an application, and as a consequence, some fundamental areas of science may be neglected. While in the long term, computer science needs to expand in AFOSR, the immediate need is to focus on fundamental problems that will advance scientific computing for AFOSR.

Program Review

When the diversity of this field and the limitations of a modest budget ($1.77 million for FY 1987) are considered, the AFOSR program can be seen to have considerable breadth. The 10 to 15 contracts typically funded in the last 3 years cover topics in algorithms for parallel computing and supercomputers, distributed and concurrent computing, environments for computing, fault tolerance and reliability, databases, and automatic programming and languages. The PIs supported are, by reputation or personal knowledge, among the top in their fields. The changes in the program between 1985 and 1987 are evidence of a careful management of resources.

The program seems to have a slight emphasis on computer science research that develops the ideas and tools needed for the effective use of the next generation of computer architectures. The Subpanel believes that this is appropriate. If additions are made to the program, it would be valuable to do them with this or some other unifying goal in mind.

ARTIFICIAL INTELLIGENCE

Overview

This program funds work on extending the scientific basis for artificial intelligence technology in the context of Air Force relevant applications. Among the goals of the program are problem solving, comprehension, and learning in expert systems; parallel architectures for AI computations; hierarchical and hybrid architectures for image understanding; mathematical models of learning and perception; computer generated; text and robust natural languages interfaces.

For the benefit of readers who are not well acquainted with artificial intelligence, some basic issues in AI research are discussed at the end of this Subpanel II report.

Program Review

The Artificial Intelligence Program is a small, but not an insignificant portion of the federal funding for basic AI research. The core research program is funded at $2.2 million for FY 1987 and the program is involved in an additional $1,500,000 of FY 1987 support, including the Northeast AI Consortium (NAIC) and a joint initiative in artificial neural networks.

Given the small budget, a reasonable breadth of projects is being supported including six in computer vision, four in expert systems, three in parallel and connectionists architectures, two in planning, and one each in natural language, robot control, symbolic algebra, and logic programming. Two of these projects could also be considered to be in knowledge representation. Within the NAIC, the AFOSR Artificial Intelligence Program supports projects in architectures for knowledge-based systems, logic programming, and planning. On the whole, the researchers being supported have excellent reputations in the field.

With additional funding, the Artificial Intelligence Program could use expansion in the areas of natural language, knowledge representation

including belief systems (e.g., modeling a pilot's beliefs of the beliefsand intentions of opposing pilots), reasoning, and learning.

It should be noted that AI is also being supported within the Information Processing and Artificial Intelligence Program of the Electronic and Material Sciences Directorate and within the Cognitive Science Program of the Life Sciences Directorate.

CONCLUSIONS AND RECOMMENDATIONS FOR ALL PROGRAMS REVIEWED BY SUBPANEL II

The Subpanel is favorably impressed with the way the program managers have chosen to allocate the budgets of the programs which they shape and guide over extended periods of one or two years and more. We are pleased to hear of the selection of a permanent, nonrotating manager for the Computer Science and Artificial Intelligence programs. It is particularly appropriate for computer science that the transfer of technology from basic research in these areas typically requires an extended involvement of the research group and its management. The manager will permit a continuous representation of the interests of the Information Science part of the Directorate.

The Subpanel is enthusiastic about the possibility of a future initiative centered on robotics. This has obvious relevance to some Air Force needs. Internally it could serve as a valuable catalyst to bring together managers, researchers, Air Force laboratory personnel, and more than one directorate. (A possible robotics initiative is also mentioned in the Dynamics and Control section of the Subpanel I report.) If carefully guided, such a project can produce an increase in respect for and appreciation of work in other, perhaps alien, groups. Specifically, a project in robotics involves automatic control and sensing, vision, planning and reasoning, distributed computing, and massive number crunching.

Several Air Force laboratories are engaged in tasks that are closely coordinated with the programs associated with this Subpanel. (Some details are given in the program reviews.) Here we want to record our perception that, when properly orchestrated, the labs can be as helpful to the investigators as to the program managers. When a lab already has expertise in the topic, collaboration can proceed, but when it is lacking we would like to suggest that appropriate personnel be sent to strong academic centers for extra training so that there will be in-house expertise for any substantial project.

We conclude this Subpanel report by suggesting a research topic that is at the interface of computer science and scientific computing, and with answers to some questions about artificial intelligence that were posed to the Panel.

A Useful Research Topic in Computer Science

There is a need to design compilers, operating systems, and environments that are friendly to scientific computing.

Fortran codes are filled with IF statements designed to avoid conditions that the language or operating system declares to be unacceptable despite the fact that mathematically they cause no harm. For example, in a recurrence, a division by zero gives rise to infinity, which, a split second later, may get reciprocated to produce a harmless Zero. Not all infinities created in a recurrence can be expected to vanish in this way. However, an important variable may be tested, <u>outside</u> a pipeline or inner loop, to see whether it is infinite or not. Applications codes could be simpler and cheaper if the floating point numbers were completed with infinity. The recently approved IEEE floating point standard includes infinity and even more useful objects. Several floating-point chips conform to the full IEEE standard but the languages and operating systems have not yet been modified to accept these new quantities. The technical difficulties here are quite profound. The quantity Nan (Not a number) changes the floating point system from a totally ordered one to a partially ordered one. The resulting complications to comparisons (e.g., <) require very careful handling. Yet Nans provide excellent debugging mechanisms, particularly in pipelined environments. The result of the operation 0/0 can be a Nan pointing to the guilty line of code. It can propagate unchanged through a loop and be interrogated at a suitable place in the program.

Another related project is the provision of debugging aids for parallel computations. It is quite possible that debugging could be as significant a cost as communication in tomorrow's computing environment. Then, at last, debugging will be recognized as an important intellectual activity and will emerge from the closet.

The reason for giving this much detail is that, in its absence, the subject proposed here is all too easily classified as an application of computer science techniques to number crunching. As such it is not recognized as fundamental, conceptual research. Such misperceptions occur too often in the newer disciplines of computer science and artificial intelligence.

Basic Issues in Artificial Intelligence Research

The following are answers to some specific questions posed to the Subpanel.

1. What are the basic research issues of AI?

A common definition of AI is "the investigation of how to program computers so that they behave in ways attributed to intelligence when observed in humans." One can identify three goals of AI research: (1) Computational Psychology, to understand human cognitive behavior by experimenting with computer models; (2) Computational Philosophy, to understand the nature of intelligence by experimenting with computer models that are intended to exhibit intelligent behavior even if not human-like; and (3) Advanced Computer Science Engineering, to expand the domain of behaviors we know how to program computers to perform to include more behaviors that previously only humans could do.

The basic research issues are those that would make fundamental advances in attaining those goals.

One may get some idea of the structure of the field by considering the organization of the Fifth National Conference on Artificial Intelligence held in August 1986.

Science	Engineering
Automated Reasoning	AI and Education
Automatic Programming	AI Languages and Architectures
Planning	Applications
Qualitative Reasoning & Diagnosis	Automated Reasoning
Search	Knowledge Acquisition
Theorem Proving	Knowledge Representation
Uncertainty and Expert Systems	Learning
Cognitive Modeling and Education	Natural Language
Knowledge Representation	Robotics
Learning	Vision and Signal Understanding
Natural Language	
Perception and Robotics	

This was the first time a major AI conference was divided into science and engineering tracks, but, even though many people thought that it was often difficult to decide in which track a particular paper belonged, it will not be the last time.

2. How should one distinguish basic research in AI from applied technology?

It is not easy to make clear the difference between making an advance in discovering how to program a behavior that no one knew how to program before, and merely writing a program that nobody bothered to write before. The former is an advance in basic AI research, the latter is an exercise in applied technology. Basic AI research often leads to new programming methodologies, new programming languages, new control structures, and new data structures. These are the packaging and the conceptual chunking of ideas developed to tackle new domains of behavior. The use of these packaged techniques to write new programs is applied AI, or just standard programming, depending on how widespread the knowledge of these techniques has become.

3. Is this field an application of computer science, or a fundamental field of research?

AI is a fundamental field of research, not an application of computer science. One could even make an argument that much of computer science is an application of AI. As the list of goals above suggests, the basic question of AI is, "Is intelligence computable?" This question cannot be answered theoretically because "intelligence" cannot be defined at the present time. For the moment, we can only say that it is a term used by people to characterize certain behaviors. We can outline those behaviors, and, indeed they do form the subareas of AI listed above among the science and engineering tracks of the Fifth National Conference on Artificial Intelligence. AI, as an experimental science, is engaged in the clarification of the nature of intelligence, using specification by computational procedure as its methodology. As AI researchers proceed, we are getting a better understanding of what intelligence is, and spin-offs of the research, including computational techniques, data structures, and programming languages, are being applied to help solve present-day problems.

REPORT OF SUBPANEL III

Hirsh G. Cohen
Nancy J. Kopell
Joel Spruck

PHYSICAL MATHEMATICS AND APPLIED ANALYSIS

These two related programs are managed by the same, permanent program manager. In this Subpanel III report the two programs are reviewed together. The main task areas covered in the Physical Mathematics Program consist of bifurcation and chaotic phenomena, soliton and pulse type waves, shock waves and singularities, and "modeling." The modeling efforts cover a range of subjects including fluid mechanics, combustion, semiconductors, neural nets, metallurgy, and diffusion processes. The Applied Analysis Program, which began in 1985, consists in large part in the study of the mathematical properties of the differential equations modeling physical processes. In addition, it contains several different efforts aimed at the solution of inverse problems in the areas of acoustic and electromagnetic scattering, and x-ray tomography. As mentioned elsewhere in this report, in addition to the core programs in Physical Mathematics and Applied Analysis, two large research groups are currently supported by URI contracts: one on modeling, analysis and simulation (including nonlinear optics and fluid dynamics) at the University of Arizona, the other on heterogeneous and nonlinear media at the Courant Institute.

Program Review

The budgets for these two programs are about equal: $970,000 for Physical Mathematics and $850,000 for Applied Analysis for FY 1987. The Physical Mathematics Program is the older and better established of the two. Its investigators are generally at a very high level. Furthermore, there is a cohesiveness in the main task areas which allows the program to have a noticeable impact on scientific progress in these task areas. The Applied Analysis Program, being younger, has not yet achieved the cohesiveness or quite the quality of Physical Mathematics. However, it supports many high-level and successful efforts of investigators in areas of partial differential equations that are important to physical problems.

The two programs appear to be managed knowledgeably and effectively. Recent efforts to create liaisons and research connections between principal investigators and Air Force laboratories have been energetically pursued. The Applied Analysis Program has grown dramatically, and new research opportunities relevant to the Air Force have been identified.

A new initiative in nonlinear science has been approved for FY 1988. An initiative on deterministic and stochastic methods for inverse problems, which also involves the Probability and Statistics Program, has been approved for FY 1989.

RELATIONS WITH AIR FORCE LABORATORIES

The Program Manager is knowledgeable about technical programs at the laboratories. He has visited a number of the labs, including Wright-Patterson, Eglin, and Kirtland, and has established good technical liaison. In addition, he has been involved with technical programs with the School for Aerospace Medicine in San Antonio and the Geophysical Lab in Cambridge, Massachusetts. A good base has been established for future technology transfer as well as exchanges of research problems and results.

Combustion research, supported in the Physical Mathematics Program for some time, has proven to be of direct use in understanding flame behavior in work at Wright-Patterson. Inelastic fracture problems at that laboratory have stimulated a new research initiative in meso-mechanics. The interest in small scale material behavior at Wright-Patterson has also helped to point the Physical Mathematics Program toward new mathematical work on metallurgical crystalline behavior and crystal growth. Wright-Patterson's interests in hypersonic flow for future winged flight, military and commercial, may be a good base for a future mathematical support program in both analytical and numerical work in this flow regime aimed eventually at design capability.

This connection and collaboration with Wright-Patterson has been strengthened through participation in the AFOSR Mathematics Workshop at that laboratory in September 1987. The topics of this workshop will include aircraft control and fluid mechanics.

At Eglin, nondestructive evaluation of material behavior during explosions is needed. This was one of the motives and also one of the supports for the new FY 1989 initiative on inverse problems. The program manager's relations with the Department of Energy laboratory for nondestructive testing at Ames, Iowa, have already been useful in this same regard.

The current central topic of interest at Kirtland is nonlinear optics. Contacts have been arranged between personnel at the Air Force center of excellence in this field at Kirtland and the AFOSR-supported URI center at the University of Arizona in nonlinear optics. This URI center is well equipped to do both mathematical analyses and large scale calculations.

Useful working contacts have been established at the Geophysics Lab and the School of Aerospace Medicine. At the former there are interests in high altitude plasma physics and its mathematical characterization (e.g., wave propagation), and these can be related to investigators in the Physical Mathematics Program. Concerns with radiative effects, physiological behavior under high gravity forces, and asymptomatic heart problems may stimulate research problems in mathematical physiology.

In summary, in a very short period of time, through the direct energetic activity of the program manager, these programs have become known to the Air Force labs, and the needs of the labs are beginning to be understood by a number of scientists being supported. This excellent beginning should be continued.

RECOMMENDATIONS CONCERNING FUTURE DIRECTIONS

Current Initiatives

The two initiatives for FY 1988 and FY 1989 will serve well to set part of the future direction for these programs. The initiative in nonlinear sciences will allow for further development in the analytical techniques to handle partial differential equations. Work such as that in conservation laws for equations of mixed type should be enhanced, with more researchers brought into the area. The mathematical techniques required for the new physical conditions needed in moving boundary problems need to be addressed. A number of physical, chemical, and biological problems need to be addressed, for example the physiological problems at extreme gravity, altitude, and radiation conditions mentioned earlier. The initiative should allow for qualitative study, solution technique development, and special problem solving.

The initiative on inverse problems should enlarge the collection of methods and problems that these programs have begun to support. Nondestructive testing and evaluation with acoustic, electromagnetic, and optical methods have mathematical representations and are ripe for further development. The radar detection problem is an inverse problem in electromagnetic scattering. The three-dimensional version of this problem is unresolved; it is difficult but important for both military and commercial use.

Future Initiatives

1. As mentioned earlier in describing laboratory problems, the Air Force, as with other government and industrial technological enterprises, requires new materials and new ways of materials processing and testing. Thermal, radiation, dynamic force effects, cracks, and fractures are examples of continuing needs. Of even greater interest are new materials: polymers, ceramics, liquid crystals, new "active" materials (semiconducting and superconducting) in electronics that involve crystal growth, and other similar metallurgical needs at the crystalline level. All of these will require new mathematical representations and the development of mathematical methods so as to understand material behavior and to be able to calculate material designs, even at microscopic levels.

A start has been made in several of the investigations now being supported--crystal growth, crystalline geometry, and energy effects. There is ample evidence that mathematicians have much to contribute. These few research activities also show that this is an area where good collaboration can be formed between mathematicians and materials scientists.

Recommendation. A new initiative in the mathematics of materials science is theref :e proposed.

2. Discussions with the Program Manager have shown that there is central interest in the Air Force for the development of hypersonic airplanes. This development will serve expected military needs and can obviously lead directly to commercial applications. Hypersonic flows, and high-speed flows in general, have for many years been the subject of fairly intensive experimental and theoretical investigation. This should now move forward towards a mathematical representation of hypersonic flows past airfoils and other bodies that will allow for efficient (even optimal) design calculations. This essentially involves creating theoretical and calculational methods for the inverse problem: e.g., find the airfoil shape that yields optimal flow patterns (drag, lift, heating, etc.). This mathematical design methodology has been successfully achieved in transonic flow.

Recommendation. A new initiative in mathematical design techniques for very high speed flows should be developed.

APPENDIX I

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
MATHEMATICAL AND INFORMATION SCIENCES DIRECTORATE

AREA	PROGRAM MANAGER	FY 87 BUDGET
Dynamics & Control	Maj. James Crowley	$3.09 M
Communications & Signal Processing	Maj. Brian Woodruff	$0.87 M
Mathematics of Physical Systems	Dr. Arje Nachman	$0.97 M
Applied Analysis	Dr. Arje Nachman	$0.85 M
Optimization	Dr. Sam Rankin	$1.10 M
Finite Mathematics	Dr. Sam Rankin	$0.75 M
Computational Mathematics	Capt. John Thomas	$3.01 M
Probability & Statistics	Maj. Brian Woodruff	$2.91 M
Artificial Intelligence	Dr. Vincent Sigillito	$2.12 M
Computer Science	Dr. Vincent Sigillito	$1.77 M

APPENDIX II

UNIVERSITY RESEARCH INITIATIVE (URI) PROGRAMS FUNDED BY THE MATHEMATICAL AND INFORMATION SCIENCES DIRECTORATE, FY 87

U. of Arizona	Modeling, analysis, and simulation	$550 K
New York University (Courant Institute)	Nonhomogenous media	$391 K
U. of Maryland	Control of complex multibody spacecraft	$345 K
Brown University	Distributed parameter control	$650 K
U. of Illinois	Parallel processing	$850 K

APPENDIX III

THE ROLE OF BASIC RESEARCH IN APPLIED SCIENCES IN A MISSION AGENCY

The Air Force Office of Scientific Research (AFOSR) supports basic research in a rather broad spectrum of areas of mathematical and information sciences. Many of the mathematical science areas supported are termed "applied mathematics," both for their close identification with real world applications and for certain historical reasons in the development of mathematics. Distinctions of this kind can lead to misunderstandings about the respective roles of basic science, applied science, and development. One might even ask: how can there be basic research in applied mathematics?

This appendix addresses the importance of support for basic research in applied sciences. The field of statistics is used as an illustration.

What distinguishes basic science, applied science, or theoretical engineering from development and production is that in basic research, the eventual usefulness, if any, may be a long time off. The objective is generally a deeper understanding, whereas in development, the objective is to get the job done quickly and economically. The distinction between understanding and timeliness is hazy because many people combine several of the above-mentioned functions in their work. Moreover, a serious attempt to sharpen the distinction and to separate the tasks would interfere seriously with the effectiveness of the work by reducing the communication vital for success. Attempts to divorce applied sciences from applications have often tended to lead to sterile science. Applied sciences derive their inspiration and force from applied problems demanding meaningful answers. Nonetheless, these sciences, insofar as they seek general insights and understanding, are basic sciences.

Consider the field of statistics. This is a science that is fundamentally tied to applications. In its most philosophical and theoretical domain, it deals with the question of how one learns from experimental information. This question lies at the heart of scientific inference, but nevertheless has applications to other fields of inquiry as its object. Applied though it is, the investigation of such questions constitutes proper scientific inquiry and is as basic as research in number theory or gravitation.

A strong scientific infrastructure is essential if development is to proceed properly, and it is important that the Air Force help support such an infrastructure. An illustration of the consequences of a weakened infrastructure is provided by the history of quality control, which was developed as a statistical science. Up through World War II and into the 1950s, statisticians were involved in advancing this flourishing and economically important field. Around that time, applications of quality control were taken over mainly by engineers who were not particularly well trained in statistics and who regarded statistical quality control as a finished subject. Communication with statisticians was neglected by both groups, and by and large, statisticians in the United States no longer paid attention to this field. Both the practice and the science of quality control suffered in this country as a result, and it is only recently that interest and progress have revived.

A strong scientific infrastructure can be maintained by supporting basic scientific work of high quality. For the purposes of AFOSR, it is desirable to support basic research, which may eventually be relevant to the needs of the Air Force. In that way, there is incentive for both the scientific and user communities to communicate, to the advantage of both. The mechanism of scientific initiatives, judiciously selected and vigorously pursued, can help to focus activity, lead to richer interactions, and make a substantial impact in the sciences.